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AFGWC SNOW ANALYSIS MODEL

BY

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AIR FORCE GLOBAL WEATHER CENTRAL
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The AFGWC Snow Analysis Model, which generates daily snow age and depth analyses, has been operational since March 1975 for the Northern Hemisphere and October 1975 for the Southern Hemisphere. The snow analysis (SNODEP) model uses the latest observations (surface synoptic reports), snow and ice climatology, time continuity and manual updates. This makes it possible to produce very good measures of snow extent and reasonable snow depth values at all grid points over the land and the ice-covered areas of the earth, regardless of the availability of surface observations. The method of analysis, a technique used to infer snow age, and some problems associated with the input data are described. Although the model is tailored to satisfy specific AFGWC requirements, other potential applications are discussed.

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1. INTRODUCTION

The AFGWC Snow Analysis Model, which generates daily snow age and depth analyses, has been operational since March 1975 for the Northern Hemisphere and October 1975 for the Southern Hemisphere. The snow analysis (SNODEP) model uses the latest observations (surface synoptic reports), snow and ice climatology, time continuity and manual updates. This makes it possible to produce very good measures of snow extent and reasonable snow depth values at all grid points over the land and the ice-covered areas of the earth, regardless of the availability of surface observations.

The method of analysis, a technique used to infer snow age, and some problems associated with the input data are described. Although the model is tailored to satisfy specific AFGWC requirements, other potential applications are discussed.

2. ANALYSIS GRID

2.1 Resolution.

The analysis grid used in SNODEP was originally designed for the AFGWC Three-Dimensional Nephanalysis (3DNEPH) Model (Reference 7) and is shown in Figure 1 for the Northern Hemisphere and in Figure 2 for the Southern Hemisphere. In August 1983, the 3DNEPH was replaced by the Real-Time Nephanalysis (RTNEPH) Model; however, the same grid structure was retained. Each of the 64 3DNEPH/RTNEPH boxes contains 4096 grid points in a 64 by 64 array, resulting in a horizontal resolution of approximately 25 nautical miles.

2.2 Analysis Areas.

The snow analysis is generated for the boxes outlined with a dark border shown in Figures 1 and 2. Totally water-covered boxes are not considered unless they are in areas of ice potential. Boxes containing land masses which have no record of snow reports and no snow climatology points are not considered.

3. SNOW ANALYSIS INPUT

3.1 Surface Observations.

The latest 24 hours of surface observations for each reporting station are used in the initial snow depth analysis. Snow depth reports for any hour in the 24-hour analysis interval are considered and are updated by additional snowfall data or decreased by calculated snow melt. If an actual snow depth is not reported, a 24-hour change is calculated using the six-hour snow accumulation, present weather, temperature, or state of the ground. Each of these parameters is used in the following manner.

The six-hour snow accumulations, if available, may be used directly and summed over the 24 hours. Every effort is made to account for all hours and to avoid counting an accumulation twice. When there are six hours or less between reports with six-hour accumulations, a linear portion of the accumulation is used. If the reports are more than six hours apart, the present weather, if available, is used to fill the void.

An hourly accumulation table was developed to relate the WMO Present Weather Code 4677 (References 6, 7) to snow accumulation. Table 1 shows hourly accumulations associated with the coded values.

Present Weather (WMO Code 4677)	Hourly Accumulation (Inches)
22,26	0.1
71	0.5
72	0.1
73	1.0
74	0.5
75	2.0
79, 84, 85	0.7

Table 1. Hourly Accumulation Conversion for WMO Present Weather Codes.

Accumulation rates were based on a scale used by AFGWC forecasters and described in a NOAA Technical Memorandum (Reference 12). The accumulation rates are reduced when temperatures are between 32° and 38°F by use of the equation

$$\text{Corrected Accumulation Rate} = (1.-(\text{FHRNHT}*0.148)*\text{IWETH}),$$

where FHRNHT is the number of degrees above 32°F and IWETH is the accumulation value from Table 1.

If no new snow depth or accumulation information is available, temperature data are used to calculate a possible snow melt. Snow melts at the approximate rate of 0.04 inches per hour per degree above 32°F, neglecting other factors such as wind speed, moisture and insolation (Reference 4). Using the melt factor and assuming a linear temperature change between observation times, the program calculates melt values over the past 24 hours.

State of the ground information from synoptic reports is used only to verify the absence of snow. The state of the ground is a code figure which describes the ground-surface conditions. When the latest report does not have a snow depth group, the program uses the state of the ground information. Zero snow is recorded for values of WMO Codes 0901 and 0975 (Reference 7) which report non-snow surface conditions.

Finally, as part of the observation retrieval, some gross error checks are made. Some stations located where snow never occurs (such as in the tropics) insert other parameters in the synoptic report supplementary group normally used for snow data. A four-step approach eliminates introduction of these data. First, the AFGWC surface decoder deletes known non-snow data. Second, observations from stations where snow never occurs are not accepted. Third, a relationship was developed between temperature, elevation and latitude to eliminate a snow report where snow is obviously impossible (if the sum of Temperature (°F) - Elevation (1000's Ft) - Latitude (°)/3 is greater than 40, a snow report is rejected). This allows snow reports to be accepted at higher temperatures in higher and more poleward locations where it is possible to have snow remaining after warming occurs. Finally, reports from low-latitude, low-altitude stations during the summer months are rejected.

3.2 Land, Sea and Ice Geography.

The land/no-land geography is a "fixed" field (does not change). Sea-ice information is added to this field from weekly bulletins received from the Joint NOAA/Navy Polar Ice Center showing updated latitude-longitude coordinates of the ice. These data are integrated to form a Land/Sea Ice (LSI) geography field. This field is readily available as a part of the AFGWC nephanalysis geography data base.

The LSI geography is an important part of the snow analysis. Where there is land, the snow analysis is allowed to proceed normally. No snow accumulation is allowed over water. Over ice, an arbitrary snow-depth value of ten inches is assigned. An example of this is shown in Figure 3, with an area of ice in the lower left corner.

3.3 Continuity.

The previous day's snow depth analysis is used as a basis for computing snow-depth changes when normally reported depth observations are not available during the 24-hour period. It is also used in conjunction with data to compute snow depth in areas totally devoid of observations. The use of continuity in these two cases is discussed in Section 4.

Continuity can also be used as a basis for gross error checks on the snow depth analysis. However, continuity is now used as a check only at grid points previously modified by manual input derived from satellite imagery. While yesterday's observations may be no more reliable than today's observations, yesterday's manual input is assumed correct.

3.4 Snow Climatology.

3.4.1 Original Data.

An important aspect of any climatology is its origin. The original snow depth climatology data are monthly averages from U.S. Soil Conservation Service summaries (References 9, 10, 11), a U.S. Army study of snow depth (Reference 8), and a study of Arctic snow depth (Reference 4). The USAF Environmental Technical Applications Center (ETAC) has also provided data from archived surface observations. The snow climatology field can be traced from original data, to first-guess analysis, to the manipulation of the first-guess, and then to the final analysis.

3.4.2 First-Guess Climatology.

A first-guess climatology field was established by relating snow depth to other meteorological parameters by means of a multiple regression analysis (Appendix A). This analysis showed that the square-root of the climatological snow depth was closely related to a combination of climatological surface temperatures and moisture, station elevation and latitude, terrain slopes (half-degree latitude and longitude distances to the east, north and west) and month. The resultant multiple correlation coefficient was 0.91 and accounted for 82% of the variance of the dependent sample. The final relationship was derived from experiment, hand analysis of resultant fields, and some adjustments which are described below.

3.4.3 Data Manipulation.

The data were adjusted for two reasons: to better handle zero snow depth and to better describe surface temperatures. Since zero snow depth is possible under a variety of meteorological situations, an equation was devised to create "negative snow depth" for some conditions of no snow. Varying amounts were subtracted from the depth according to the surface temperatures to produce a continuous slope in the annual snow depth curve. This modified a summer flattening of the curve at zero depth. Since surface temperatures are available on a half-mesh (100 nautical mile grid point spacing) field, another adjustment was made for actual elevations higher than the interpolated half-mesh terrain height: the surface temperatures were cooled by a standard lapse rate (-6.5°C/km) from the half-mesh terrain to the actual elevation. Both adjustments improved the correlation of the final equation which is discussed in Appendix A. The equation is used with the correlated parameters to form a first-guess snow-depth value on the AFGWC one-eighth mesh grid. The final climatological analysis starts with this first-guess climatology field.

3.4.4 Final Climatology Analysis.

The first-guess (regression) climatology field is overlaid with a Barnes-type scan (Reference 2) of station snow-depth climatology data. However, the resultant field has two limitations: in some areas, snow depth can vary greatly from one grid point to another; also, station climatology data may be far enough apart in some areas to warrant extending the area of influence of a given station. The climatological analysis uses the closest station climatology and allows it to influence points up to ten grid points away. The adjustment equation used is

$$CLIM = SNOW*EXP\ (-FACTOR*(DIST/RAD)),$$

where SNOW is the station snow depth value, FACTOR is a preset weighting factor, DIST is the distance from the station to the grid point, and RAD is the radius of influence. The influence of a given value decreases exponentially with greater distance from the report so that the first-guess remains unchanged at the maximum distance.

With the application of the Barnes-type scan for the final climatology analysis, values computed for water grid points are allowed to remain unchanged to preclude interpolation problems when using the climatology. This causes some climatological reports on islands and seacoasts to affect grid points over the ocean. For example, a Japanese observation may resemble a bull's-eye that stretches from the Sea of Japan to the Pacific. However, the final analysis snow-depth value is valid for only the land areas. In the sample of snow-depth climatology shown in Figure 4, a section of an analysis box, snow-depth values are given for water points in the lower left corner. The corresponding final analysis (Figure 3) shows that the water points are ice covered and treats them accordingly (Section 3.3).

3.5 Manual Input.

The snow depth, snow age, and ice data fields may each be changed by manual input (bogused) when satellite imagery or weather charts show obvious errors in the analysis. This synthetic data is entered using a separate program which specifies the field to be changed, the new value (or amount to be added or subtracted), and latitude-longitude position. There are no problem checks or limits on the bogused value, nor is there a requirement for the use of manual input.

4. ANALYSIS

4.1 Analysis with Surface Observations.

The analysis program produces a gridded-field representation from the snow depth information received as a part of surface synoptic observations. A basic assumption in the analysis routine is that a station report is representative of conditions at the four grid points around it. Since more than one station report may be applied to an individual grid point, the amounts are accumulated and a count is kept at each point. When the summation is complete, the accumulated value is divided by the count to obtain the analysis value. The procedure for applying a station report to the grid points is based on the form of the reported snow information and its relation to climatology.

The station-report snow information may be received by the analysis program in one of three possible forms. It may be the actual snow depth at the station, a new-snow accumulation, or the amount of snow melt. How the report is used in the analysis is determined by whether the grid point to which the report will be applied had its snow-depth value bogused in the previous three days. When a grid point is bogused, a bogus flag is set to 1 and it is incremented each day during its existence. The program is designed so that a bogused analysis value will be effective for three days, unless it is overridden by specific snow-depth amounts.

4.1.1 Actual Snow Depth.

The treatment of the station report is determined by the difference between the reported value and the previous day's analysis value, and by the bogus-flag values which have been set. If the difference is less than 45 inches, the bogus flag is set to zero and the station-report value is accepted. If the difference is equal to or greater than 45 inches, the bogus flag is incremented and then checked against the value of 3. If the flag is less than 3, the station-report value is set to zero and the previous day's value is used. If the flag is equal to or greater than 3, the bogus flag is reset to zero and the report is accepted.

4.1.2 New Snow Accumulation.

The use of the new-snow accumulation is determined by the depth of the accumulation and by the bogus flags set. If the new snow is less than 30 inches, the bogus flag is set to zero and the accumulation is added to the previous day's analysis value. If the new-snow value is equal to, or greater than, 30 inches the bogus flag is incremented and checked against the value of 2. If the flag value is less than 2, the new-snow accumulation is set to zero and the previous day's analysis value is used. If the bogus-flag value is greater than 1, the flag value is reset to zero and the new accumulation is added to the previous day's analysis.

If the snow word is missing from a station report the model uses the previous day's analysis at the four surrounding grid points. In cases of missing data the model will make no assumptions about snow removal and will use continuity at the affected grid points.

4.1.3 Snow Melt.

Similar to determination of new-snow accumulation, snow melt depends on the amount of melt and status of the bogus flag. If the melt is less than 15 inches, the bogus flag is set to zero and the melt is subtracted from the previous day's analysis value. If the melt is equal to or greater than 15 inches, the bogus flag is incremented and checked against the value of 2. If the flag is equal to 2, the reported value is set to zero and the previous day's analysis value is used. If the flag is not equal to 2, the melt is subtracted from yesterday's analysis.

After the basic analysis is completed, the influence of a station report is extrapolated to adjacent grid points which have no data. This option is taken because of the sparsity of data. The resulting analysis is left unchanged where there are no influencing station reports.

4.2 Analysis Without Surface Observations.

In the absence of observations and bogused data, an alternate analysis scheme is employed. In this scheme, decisions are made depending upon the values of yesterday's analysis and the climatology. If both of these values are zero, the depth is set to zero. If both of these values are non-zero, but equal, the depth is set to yesterday's value. Otherwise, the depth is set to yesterday's depth plus a factor times the signed difference between yesterday's depth and climatology. This factor is currently 0.1, and was empirically determined. Hence, in the absence of observations, the analysis (at points that have not been bogused) grows toward climatology.

For a non-observation grid point that has been bogused, the bogus value determines the treatment of that point. If the snow depth has been bogused to zero, the analysis will not be allowed to grow toward climatology. If the snow depth has been bogused to a value other than zero, the bogus flag is turned off and the snow depth is allowed to grow toward climatology. This approach eliminates the problem of snow re-accumulating in areas where it was manually deleted, particularly on the first day of the month when the new monthly snow-depth climatology is put into use.

5. SNOW AGE

Snow age (in days) is calculated for each grid point where the snow depth is greater than one inch. Figure 5 is an example of the snow age for the analysis shown in Figure 3. When the depth initially reaches more than one inch, the age count is initialized at one day; when there is new snow of more than an inch, the count is reinitialized. These decisions are made regardless of whether the depth is calculated from observational data or from climatology and continuity. As long as there is one inch or more of snow on the ground without one inch of new snow, the age is incremented up to a maximum of 365 days and stays at that value until it is reinitialized by a new snowfall of at least one inch.

6. PROBLEMS

The snow analysis model continues to be an evolving program. Each area of the model has unique problems which are treated accordingly.

6.1 Surface Observation Problems.

There are two types of problems with surface observations: systematic errors and random errors. Systematic errors appear in the data from stations where snow never occurs. Some of these stations consistently report other meteorological parameters in the supplementary group normally used for snow data. The current method of avoiding this was discussed in Section 3.2.

Random errors are more difficult to handle. They occur when a station, in the midst of a known snow area, consistently fails to report snow, or when a station reports large amounts of snow for a number of days and then reports no snow for several days with no discernible snow melt. This problem with surface observations can be attributed to encoding or communications difficulties at any of the intermediate facilities between the observer and the AFGWC data base. Random errors can be minimized with combined manual quality control and gross error checks.

6.2 Snow Climatology Problems.

Since the snow-depth climatology was originally established, the climatological problem has been the attempt to describe a quantity that varies both geographically and temporally with a monthly average value. For the snow-depth climatology the principal problem was the use of the regression equation first-guess. Although far superior to no information at all, the first-guess field had significant errors in observation-sparse areas. The regression equation emphasized surface temperature and elevation. Moisture had a minor influence since mountainous areas climatologically can have low moisture and deep snow, particularly at higher latitudes. The solution to this problem required manual updating of the climatology fields.

In the spring of 1978, the fields were updated using climatological data from USAFETAC. Additional manual input yielded snow-depth climatology fields which were too smooth. The smoothness problem for the Northern Hemisphere was remedied in 1985 by manually restoring a granularity more representative of the terrain at the 25 nm grid spacing.

6.3 Snow Age Problems.

Problems arise in calculating the snow age for those grid points where there are surface observations, as well as for those points where there are no surface observations. At grid points where there are surface observations, the snow age is initialized to 1 day with the addition of at least one inch of new snow. Thus the snow age actually represents the age of the most recent snowfall, an AFGWC requirement, and not the total age of the snow on the ground at that point. At some time in the future, with data base expansion, it is possible that the total snow age at a point will be added.

For the grid points where there are no surface observations, the snow age is initialized to 1 day when those grid points first have a snow. When the age count reaches 19 days, it is reinitialized to 1. Since the age count at climatology points is not related to actual snowfall, the count at these points is not a representative value of snow age and exists only for purposes of manual input to the analysis, where a value other than zero is required.

7. APPLICATIONS

The snow analysis model was designed to produce an automated snow analysis which would maintain a current snow-cover data base. There are many possible applications including water resource forecasting, numerical cloud analysis, atmospheric numerical modeling, surface temperature forecasting and area forecasting.

Snow amount is an important input to water resource forecasts. The model analyzes depth on a fine enough scale in space and time to daily determine (by integration) the amount of water available and the amount of melt. These indications of available water could aid drought and flood forecasting.

It is also possible to update the radiation balance over snow for numerical models. In addition to snow area delineations, it is also possible to make some assumptions on the radiation effects due to the snow age.

Snow cover also affects the satellite brightness fields. The automated analysis of clouds with satellite imagery input requires a background brightness field. This nephanalysis brightness field is used as an input to the snow analysis to identify snow-free areas. Conversely, the background brightness can use the snow analysis to help discriminate between snow and clouds. In addition, threshold brightness values can be inferred from the age of the snow.

Finally, an indication of where there is snow can be useful when preparing area forecasts. The snow analysis can be used to help determine the effects of snow on maximum temperature, low-level moisture, and stratus and fog occurrence.

8. IMPROVEMENTS

Improvements are planned for two portions of the snow analysis: input and computations. Improvements to the input include future incorporation of SSM/I data and surface temperature data. Additionally, the climatology fields will be sent to USAFETAC for further revisions and improvements. An updated version of a completely rewritten snow-analysis model is being planned.

9. CONCLUSION

The AFGWC automated snow analysis is responsive to manual input and provides an operationally useful product. After almost ten years in service, model deficiencies have been located and improvements have been made. The favorable response of forecasters who use the snow analyses on a daily basis indicates that these fields are definitely superior to manually prepared snow cover char s. In addition, the model yields a readily accessible snow-cover database which is available for a variety of computer applications.

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APPENDIX A

CLIMATOLOGICAL REGRESSION EQUATION

The climatological regression equation resulted from correlation of all the data available at the time the SNODEP model became operational. It is:

$$SD = (117.248+9.92617*LA-0.437163*TP-0.0322636*CP+0.00178634*EL-0.000636317*ES-0.000521748*NS+0.00145382*WS+6.5048*CM)^{**2}$$

or

$$SD = 0$$

which ever is greater, where

SD = calculated snow depth (inches)

TP = surface temperature (K)

CP = condensation-pressure-spread (millibars)

EL = station elevation (feet)

ES = east terrain slope (feet per degree)

NS = north slope (feet per degree)

WS = west slope (feet per degree)

Also,

$$LA = \sin\left(\text{latitude} - \frac{\pi}{4}\right)$$

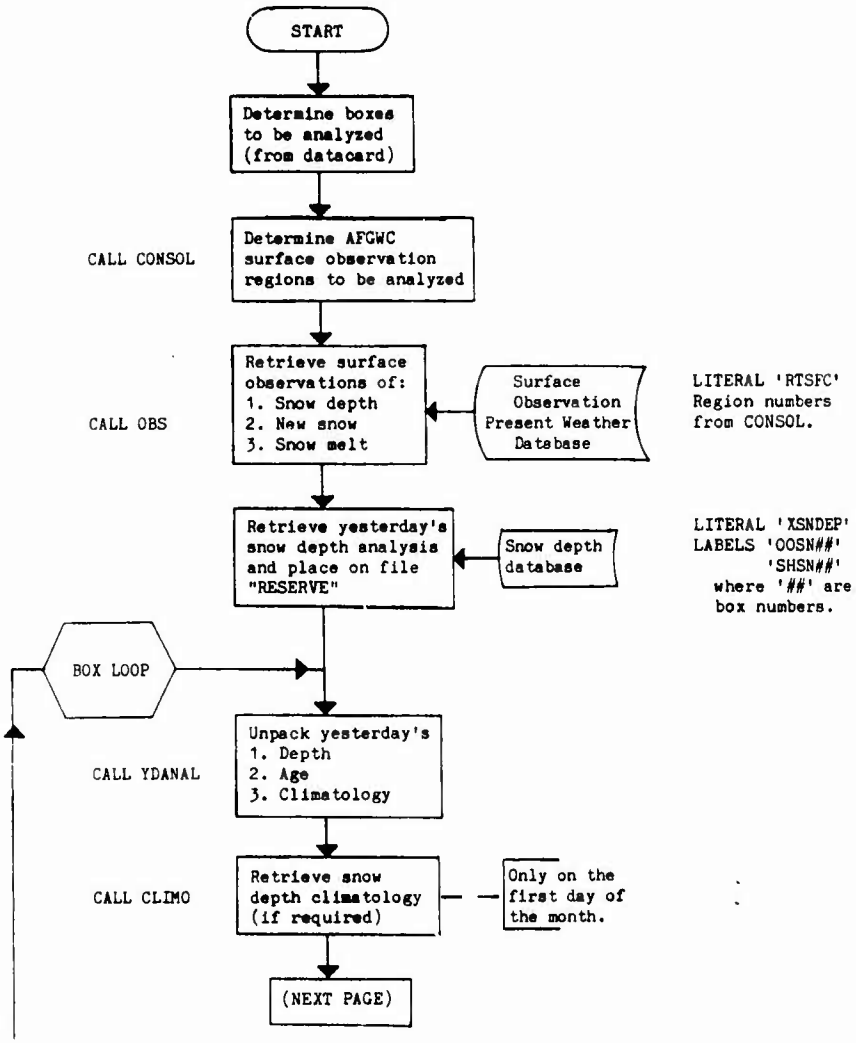
where the latitude influence is positive north of 45° and negative south of 45°. Finally,

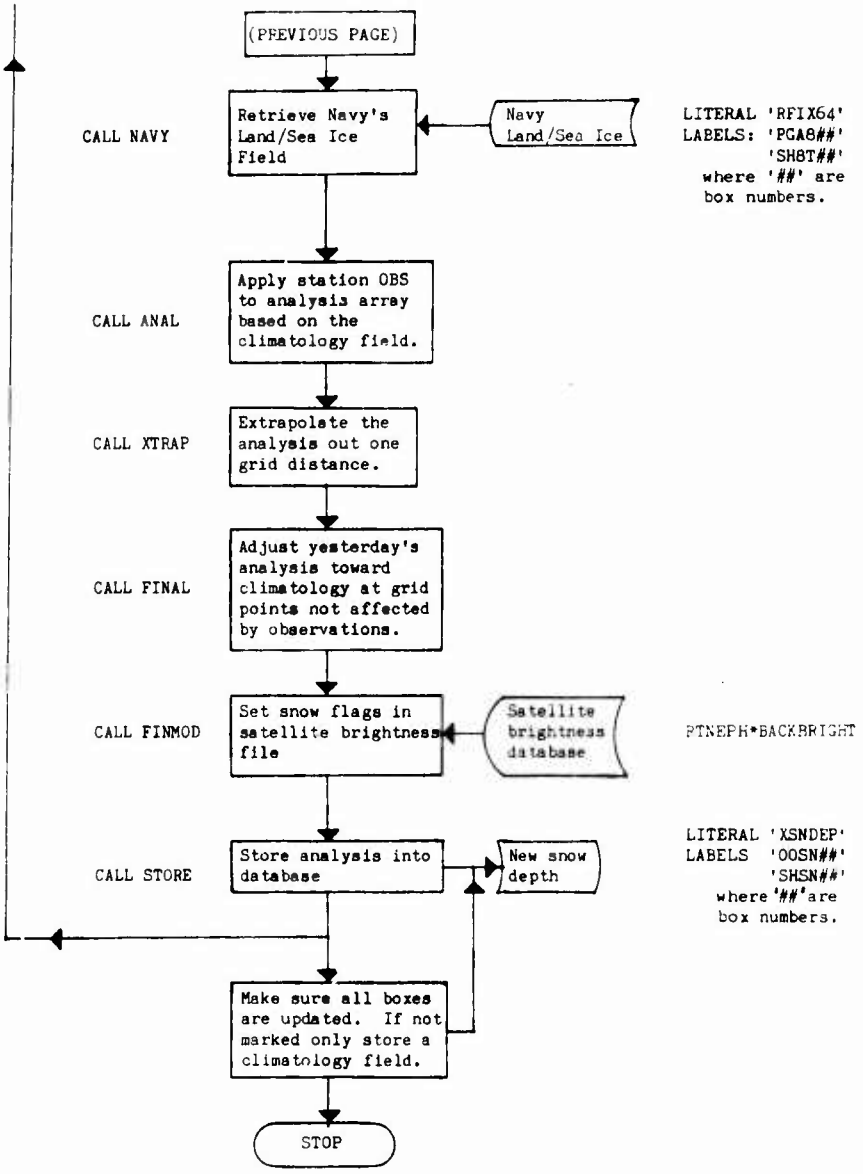
$$CM = \cos\left((\text{month} - 1)* \frac{\pi}{12} + \frac{\pi}{2}\right) + 1,$$

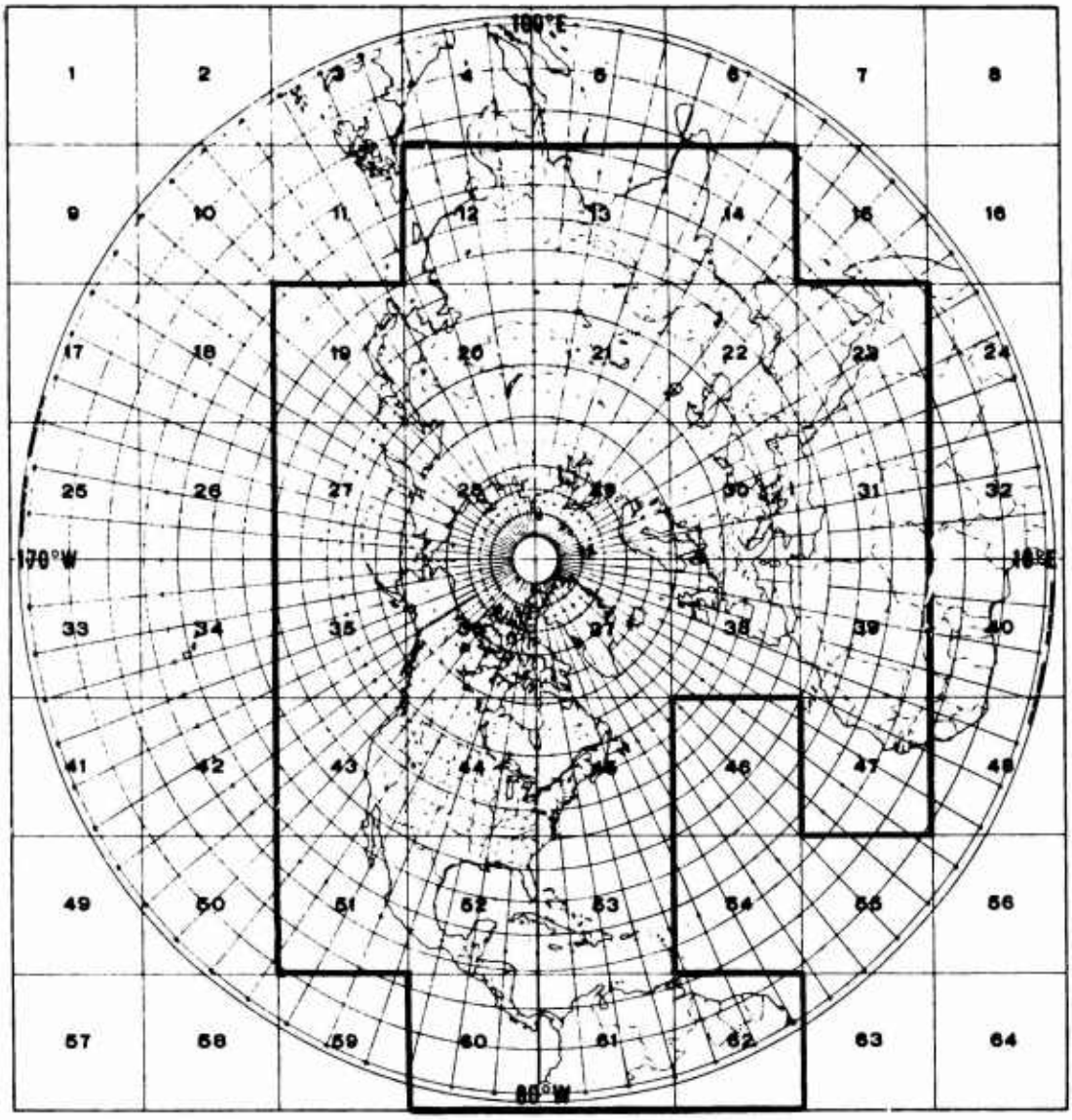
so that the monthly influence peaks in January and is at a minimum in July with no negative influence.

APPENDIX B

SNODEP FLOW CHART

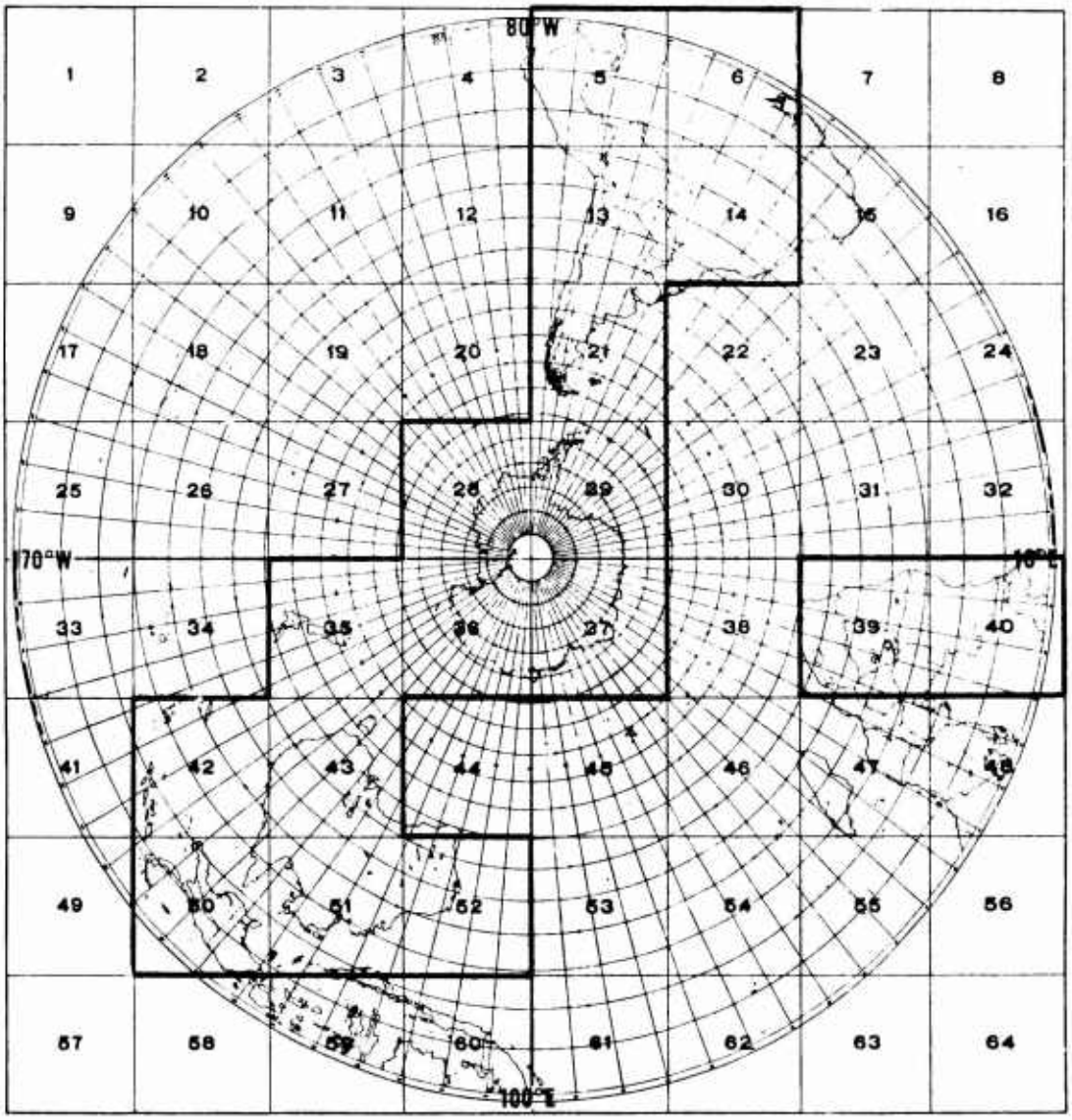



(PREVIOUS PAGE)
CALL NAVY
Retrieve Navy's Land/Sea Ice Field
Navy Land/Sea Ice
LITERAL 'RFIX64'
LABELS: 'PGA8##'
'SH8T##'
where '##' are box numbers.
CALL ANAL
Apply station OBS to analysis array based on the climatology field.
CALL XTRAP
Extrapolate the analysis out one grid distance.
CALL FINAL
Adjust yesterday's analysis toward climatology at grid points not affected by observations.
CALL FINMOD
Set snow flags in satellite brightness file
Satellite brightness database
PTNEPH*BACKBRIGHT
CALL STORE
Store analysis into database
New snow depth
LITERAL 'XSNDEP'
LABELS 'OOSN##'
'SHSN##'
where '##' are box numbers.
Make sure all boxes are updated. If not marked only store a climatology field.
STOP



NORTHERN HEMISPHERE

Figure 1. Northern Hemisphere nephanalysis grid. Snow analysis is generated for the boxes outlined with a dark border.



SOUTHERN HEMISPHERE

Figure 2. Southern Hemisphere nephanalysis grid. Snow analysis is generated for the boxes outlined with a dark border.

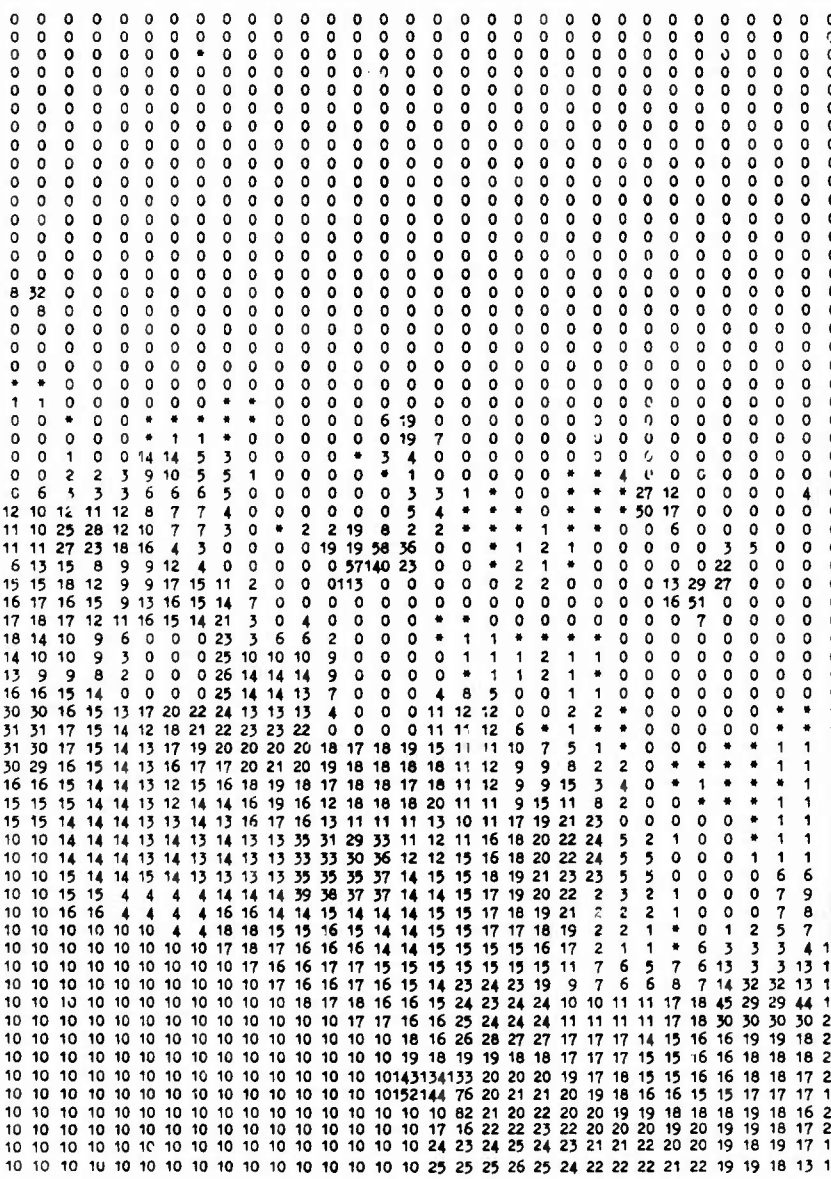


Figure 3. Snow-depth analysis example. Snow-depth values are in inches. Ice-covered water points in the lower left corner have values of 10.

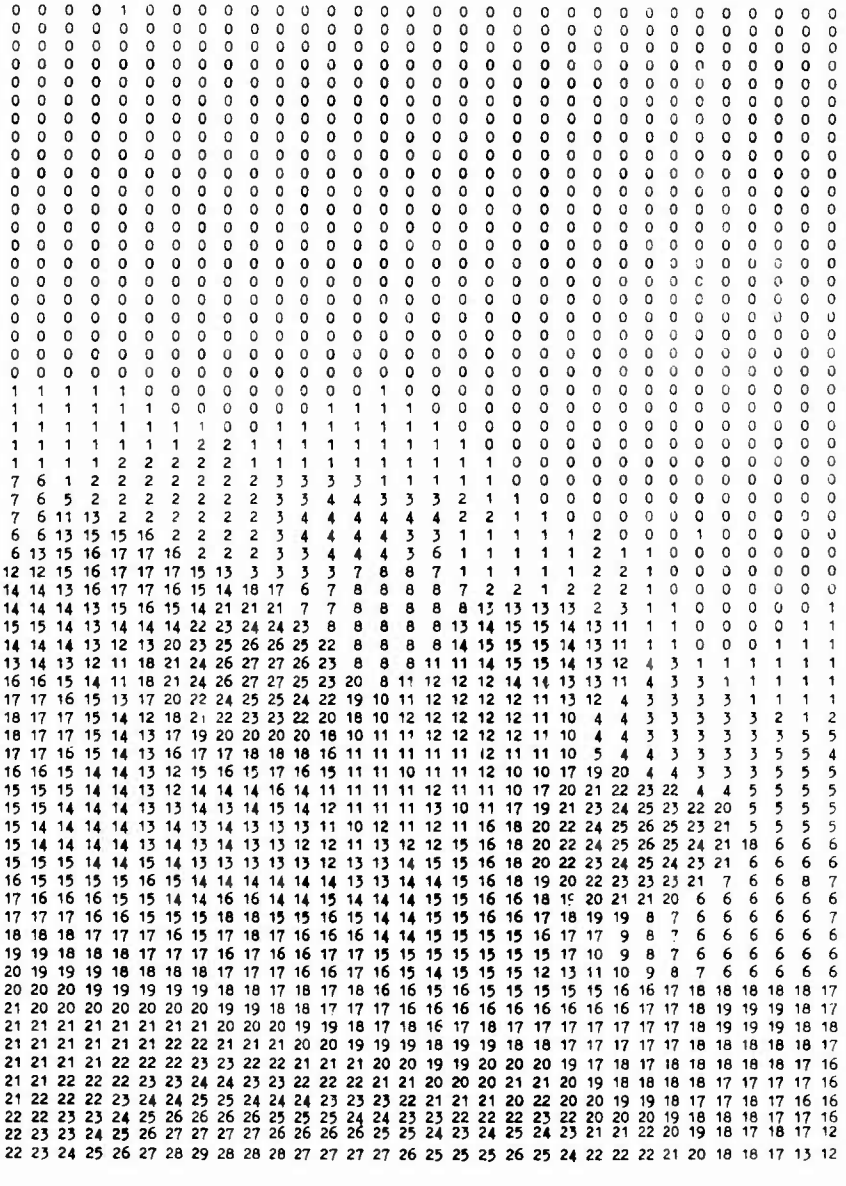


Figure 4. Snow-climatology example. The climatology values, in inches, are spread over the ice-covered water points in the lower left corner.

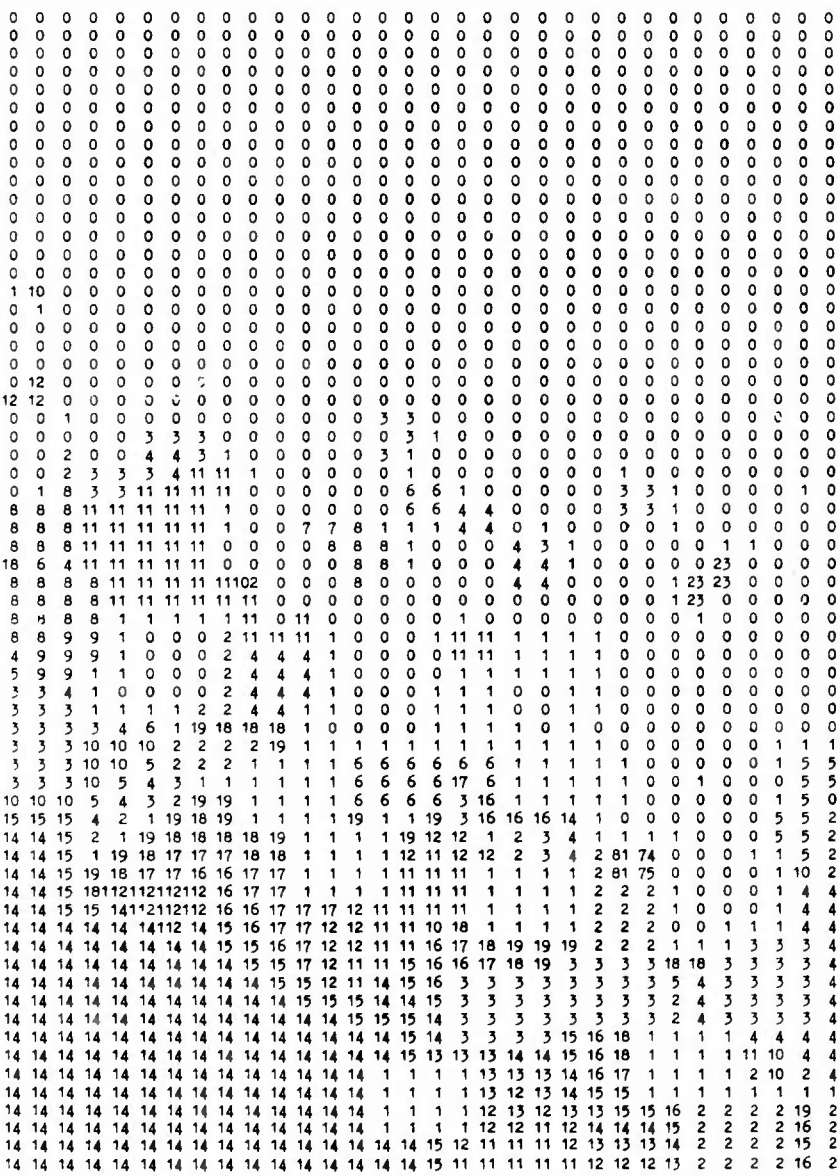


Figure 5. Snow-age analysis example. Snow age in days.

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